Anaerobic Digestion Basics

J. DeBruyn and D. Hilborn

Factsheet

ORDER NO. 07-057 AGDEX 720/400 OCTOBER 2007
(replaces OMAFRA Factsheet Anaerobic Digestion Basics, Order No. 04-097)

INTRODUCTION

Agri-food anaerobic digestion has the potential to:

- reduce odour and pathogen levels in manure
- reduce greenhouse gas production from a farmstead
- produce renewable energy
- utilize food byproducts and other organic materials sourced off-farm
- improve the fertilizer value of the manure

This Factsheet outlines some of the factors involved in deciding whether to add an anaerobic digester to a farming or food processing operation.

WHAT IS ANAEROBIC DIGESTION?

Anaerobic digestion (AD) is the process by which organic materials in an enclosed vessel are broken down by micro-organisms, in the absence of oxygen (Figure 1). Anaerobic digestion produces biogas (consisting primarily of methane and carbon dioxide). AD systems are also often referred to as "biogas systems."

Depending on the system design, biogas can be combusted to run a generator producing electricity and heat (called a co-generation system), burned as a fuel in a boiler or furnace, or cleaned and used as a natural gas replacement.

The AD process also produces a liquid effluent (called digestate) that contains all the water, all the minerals and approximately half of the carbon from the incoming materials.

Many agri-food AD systems are located on farms. Farm-based AD systems work well with liquid manure. AD systems provide a valuable manure treatment option, since most other economically effective manure treatment systems (such as composting) require solid materials with dry matter greater than 30%.

Figure 1. An on-farm anaerobic digester in Ontario.

USE OF AGRICULTURAL ANAEROBIC DIGESTION SYSTEMS

Biogas from biomass has historically been used in Asia as a fuel for household uses such as cooking. Denmark and Germany have many modern digesters operating on farms and in central locations using materials such as manure, energy crops, and food-based products and byproducts. These systems typically use biogas to produce electricity and heat.

Manure-based anaerobic digesters built in Ontario in the 1980s failed due to poor economic returns or operational difficulties. However, new technologies and control systems have seen a new deployment of agri-food anaerobic digesters. There are currently four new anaerobic digestion systems operating in the province with several in the development or construction stages. These four anaerobic digesters spread the resulting effluent (called digestate) on agricultural land. There are several other systems based on food byproducts that release their effluent to municipal sewage systems for further treatment. This Factsheet will focus primarily on systems that produce digestate for land application or capture value from the digestate in other ways.

TYPES OF ANAEROBIC DIGESTION SYSTEMS

There are two general AD system configurations suitable for agri-food systems in Canada: completely mixed and plug flow.

Completely Mixed

Completely mixed systems, as the name implies, consist of a large tank where fresh material is mixed with partially digested material (Figure 1). These systems are suitable for manure or other agri-food inputs with lower dry matter content (4%–12%). Material with higher dry matter content will work in completely mixed systems by recirculating the liquid effluent.

Plug Flow

Plug flow systems typically consist of long channels in which the manure and other inputs move along as a plug (Figure 2). These systems are suitable for thicker materials such as liquid manure with 11%–13% DM or higher.

Figure 2. Plug flow digester for dairy manure.

TEMPERATURE RANGES

There are three main temperature ranges for AD systems.

Thermophylic (50°C–60°C)

Thermophylic systems operate at a high temperature. The micro-organisms rapidly break down organic matter and produce large volumes of biogas. The quick breakdown means that the digester volume can be smaller than in other systems (average retention times in the range of 3–5 days). Greater insulation is necessary to maintain the optimum temperature range, and more energy will be consumed in heating the system. While these systems may be more sensitive to nitrogen levels in the incoming materials and to temperature variations, they are more effective in pathogen removal.

Larger, centralized systems, with more material to handle and a need for a higher level of pathogen removal, will typically run at thermophylic temperatures. Heat exchangers used to pass the heat from the effluent to the influent are more efficient at the higher temperatures (Figure 3).

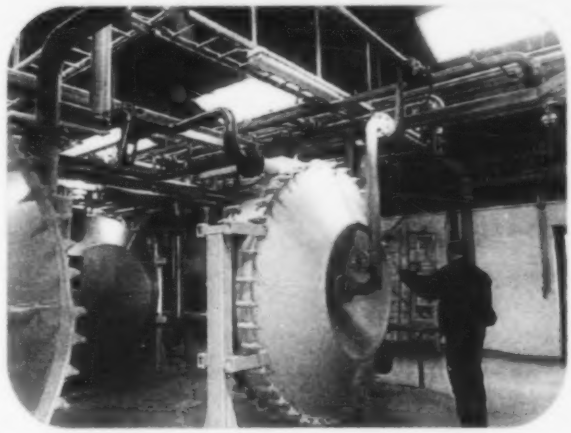

Figure 3. Heat exchanger used in a centralized thermophylic AD system in Denmark.

Mesophylic (35°C–40°C)

Mesophylic systems need a longer treatment time (retention times of at least 15–20 days or more) in order for the lower temperature micro-organisms to break down organic matter. In general, these systems are reported to be more robust when considering temperature upsets. Small and mid-sized agri-food systems will typically operate in this temperature range. Some AD systems are specifically designed to concentrate the solids content to reduce the average overall retention time needed in a mesophylic system.

Psychrophylic (15°C–25°C)

AD systems running in Quebec and Manitoba have been designed to operate in this temperature range. These systems are very stable and easy to manage, however, longer retention times are required to achieve equivalent gas production and pathogen removal.

SCALE OF AD SYSTEMS

There are three conventional options for the scale of the AD system.

Farm-Based Systems

These systems are typically designed for one farm's manure, for the manure from several nearby small farms or for the use of energy crops from local fields.

They may use lower cost components and often involve a lower level of control or complexity. Farm-based systems have been successfully operated

throughout North America and Europe. Farm-based systems at large farms may come closer to approximating centralized systems.

Some farm-based systems accept off-farm input materials such as commercial food processing byproducts. Farm-based systems will be sized to utilize the farm-based byproducts, to provide sufficient heat or power for the farm (such as at a greenhouse), or to provide surplus power to the local electrical lines.

Food Processing Systems

AD systems located at a food processing site may have similar characteristics and designs to farm-based systems, or they may be designed for removing organic matter from wastewater. Food processing systems will likely be sized to meet either the heating requirements of the facility or to manage the byproducts produced on-site or from several food processing facilities.

Centralized Systems

Centralized AD systems are found throughout Europe (Figure 4). Material from many farms and food processing plants is hauled to a centralized facility operating with a high biosecurity hauling process. Other materials, such as source-separated organics, are often added to boost gas production. Often the digestate is immediately transferred to remote field storages to allow for easier handling for land application. In many instances, heat from the centralized AD system is used nearby at another commercial facility or for heating residences.

Figure 4. Centralized AD Plant in Europe.

CHALLENGES OF ANAEROBIC DIGESTION OF MANURE

Although the fundamentals of AD systems are very simple, the operation and control can be complex. Management considerations include:

- mixing primarily fresh organic material (<1 week old) so that optimum organic matter is available for digestion
- maintaining a narrow temperature range suitable for digestion — adding material that has already cooled down in the barn or storage will increase the heating requirements
- completing proper physical design of the system to eliminate plugging, crusting or foaming problems
- optimizing the "recipe" to generate sufficient and consistent biogas production to make the economics work
- installing and managing an interrelated group of systems to safely handle heating of the tank, material flow, hydrogen sulphide reduction, methane transfer, heat production, electrical production, interconnection with the electrical grid and surplus heat management (Figure 5)

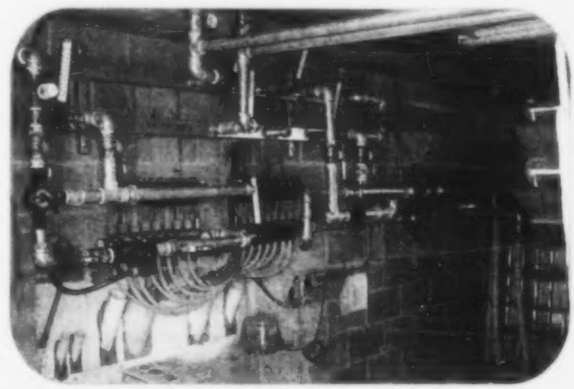

Figure 5. Anaerobic digestion systems involve a variety of control systems.

CHALLENGES WHEN PLANNING AN ANAEROBIC DIGESTION SYSTEM

When planning to build an anaerobic digestion system, considerations include:

- **Obtaining insurance:** Insurance companies may approach these systems with uncertainty — work with a known manufacturer or installer with proven designs. In Ontario, the Technical Safety Standards Association (TSSA) sets standards and processes for properly managing the biogas when it is utilized.

- **Obtaining a building permit:** Digesters are not common to the rural landscape, so obtaining necessary building permits may involve delays, including the need for possible zoning changes. Allow adequate time to address these issues.
- **Obtaining permission to accept materials:** A new AD system that accepts off-farm material may need to receive a Certificate of Approval under the *Environmental Protection Act* or an approved Nutrient Management Strategy under the *Nutrient Management Act*. Allow sufficient time for those processes as well. See below for more information.
- **Obtaining agreements to utilize energy produced:** Information below discusses options to utilize the energy.
- **Siting the facility adequate distances from conflicting uses:** An AD system is totally enclosed, and the produced biogas is typically contained, stored and utilized. However, there may be some slight odours from feedstocks and other sources. These odours may be more evident if the biogas system is constructed in an area not used to livestock production. Because the AD system reduces the odour in the effluent, the net effect for livestock facilities is anticipated to be a reduction in odour. AD facilities have been built in the U.S. for the prime reason of effective odour reduction.

MAKING THE ECONOMICS MAKE SENSE

For agri-food AD systems to be economical, there are several key considerations.

Electricity Considerations

Interconnection to the Electricity Grid

When AD systems are designed for electrical production, the system typically generates more energy than can be used on that one site. Even in cases where energy production matches on-site energy needs, an interconnection with the grid is useful (Figure 6). Energy demands at most facilities are not typically static or linear. Under normal conditions, there are peaks in energy demand that the AD co-generation system may not be responsive enough to supply. Instead, the grid essentially acts as a large battery, with the AD system putting energy in and the local facility drawing energy out.

Figure 6. Interconnection with the electricity grid.

Net Metering

Net metering is an agreement where the energy generator (the AD operator) pays the electricity distributor only for the net amount of electricity consumed. This allows the AD facility to generate electricity at any time, send it into the grid and then use electricity at any other time. The net billing or reconciliation is typically within a specified period of time (1 year in Ontario). The electricity distributor bills the facility for the net amount used. See the Ministry of Energy's Net Metering brochure for more information: www.energy.gov.on.ca/english/pdf/renewable/NetMeteringBrochure.pdf.

Standard Offer Program

The Renewable Energy Standard Offer Program (RESOP) gives some renewable energy system operations, including AD system operators, the option to sell or replace electricity at fixed rates for a period of 20 years. At the time of writing, the value of the electricity is around 11¢/kWh for non-peak electrical consumption periods and around 14.52¢/kWh for peak periods (2,000 hr/yr). These values will inflate at 20% of the Consumer Price Inflation Index. For more details, see the OMAFRA Factsheet *Anaerobic*

Digestion and the Renewable Energy Standard Offer Program, Order No. 07-051, or visit the Ontario Power Authority (OPA) website at www.powerauthority.on.ca/sop.

Use of Surplus Heat

Some manure AD systems are designed exclusively to combust biogas for heat. In addition to heating the digester, buildings or hot water, it is sometimes used to heat, dry or process agricultural feeds. The heat may have excellent application in greenhouses. Finding a use for surplus heat can be a significant contributor to making AD systems economical.

Sale of a Nutrient Byproduct

Many project proponents include the sale of the digestate nutrient end product in their budget. Niche marketing of nutrient products may be possible (Figure 7). As more systems are implemented, this economic stream may diminish. Additionally, the cost of processing the end product to a point where it is a marketable product (e.g., solid-liquid separation, evaporation, composting, nutrient blending, etc.) is an additional budget item that must be accounted for.

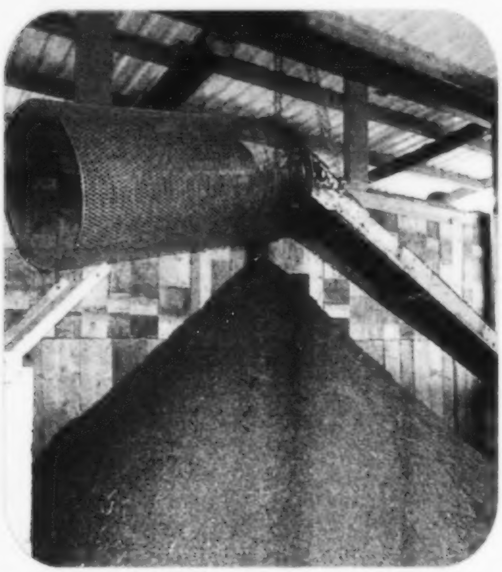

Figure 7. Generating a nutrient-rich byproduct, such as a dry compost product, may provide an economic opportunity for agri-food AD systems.

Tipping Fees

If off-farm source materials are being added to the system, AD system operators may benefit from tipping fees for those materials. These materials may also boost biogas production.

Pathogen and Odour Reduction Benefits

Agri-food AD systems remove pathogens and odour from the input materials. In the case of farm-based AD systems, the removal of pathogens and/or odour may result in a digestate that's more accceptable to neighbours than conventional, untreated manure. There is difficulty in assigning a dollar value to these intangible benefits.

Changes in Nutrient Availability

Due to the removal of readily available carbon through the breakdown of organic compounds, the effluent (digestate) contains nutrients that are more readily available for crop uptake (similar to commercial fertilizer). On the positive side, it means that the effluent will be more predictable in nutrient release, allowing the farmer to possibly reduce commercial fertilizer use more than they would have using raw manure. Conversely, the increased nutrient availability may increase nutrient loss if crops are not available for uptake. This may require longer storage or use of cover crops to hold the nutrients.

Reduction in Weed Seeds and Improvement in Effluent Handling

Farmers in Europe claim high reduction in weed seeds compared to raw manure. The reduction of weed seeds is of special importance to organic farming systems. The digested material is also easier to agitate, pump and move through small distribution pipes used in a liquid application system because of the breakdown of organic matter.

Volume Reduction

There is a volume reduction in the effluent from a digester. Approximately 1.1 kg of mass is removed from the effluent per cubic metre of gas produced. This volume reduction is relatively insignificant for manure with high moisture content. However, if manure with high dry matter content is used or other materials, such as off-farm wastes, are added, the effect can be significant.

WHAT TYPES OF INPUT MATERIALS ARE SUITABLE?

In general, many organic materials can be digested, particularly feed for animals or humans or byproducts from that feed.

Manure

Manure is simply animal feed that was not fully digested, as well as additional water and bedding. It contains significant energy that can be harvested in an anaerobic digester. The following rules of thumb should be considered:

- Digestion of dairy and cattle manure has been successfully implemented in many jurisdictions.
- Digestion of only poultry or swine manure may present more challenges because of their higher nitrogen levels — other materials may be added to optimize the blend.
- Sand or other inorganic materials will settle out in the digester and must be considered in the design. Many digesters will require shutdown and removal of built-up materials after 10 years of usage.
- AD systems work best with fresh manure — manure stored under a barn may not be as suitable.
- AD systems are not effective with highly diluted manure. Processes such as bypassing milkhouse wash water should be considered.
- AD systems can use solid manure, however, floating material and non-digestible material from livestock bedding may make the system difficult to operate.

Food Byproducts

Typically, food byproducts (and unmarketed food products) can be secured for the digester at little cost or for a tipping fee. In addition to the considerations below, see the section in this document on off-farm source material for more details.

- Most food byproducts break down rapidly in the digester.
- Optimizing the carbon:nitrogen ratio will be necessary, especially for materials with higher protein levels.
- When introducing different food byproducts, it is important to make changes to the recipe slowly to allow the micro-organisms to adapt to the new menu.
- When food byproducts come from a variety of sources (for instance, a blend of processing facilities, restaurants and retail food store materials), there may be less certainty about the consistency or quality of material compared to material from one consistent source. Agreements with reputable material handling companies are key to success.

Energy Crops

- Energy crops such as corn silage, haylage and grasses typically require on-site storage (conventional ensiling systems).
- The addition of solid energy crops to liquid systems requires specially designed solid input devices that prevent gas or liquids from escaping. These systems are commonly available in Europe.
- Energy crop addition can result in floating material, often called the floating or swimming layer. This floating layer can dry out, forming a crust that can take up digester capacity. With insufficient mixing, this crust can present a serious headache to digester operators.
- Unlike manure or many food byproducts, energy crops need to be purchased (or the cost of crop production needs to be covered by energy production).

ON-FARM MIXING OF OFF-FARM SOURCE MATERIAL

Mixing of off-farm source material with manure in an "on-farm mixed anaerobic digester" may increase biogas production. Some European jurisdictions allow mixing of up to 25% of off-farm source materials such as fats, oils and greases, pre-consumer food wastes, and other food products or byproducts. As a result of the high carbon content of these materials, biogas production can be doubled or tripled depending on the quantity and quality of the feedstock.

Proper storage of off-farm source materials is necessary to minimize the potential for odour nuisance. In addition, a blend tank may be necessary, depending on the type of AD system used. There are two regulatory systems to bring most off-farm source materials to a farm for mixing with manure in a digester: a Certificate of Approval under the *Environmental Protection Act*, or an approval under the Nutrient Management Regulation 267/03. Both of these regulatory systems have requirements for the facility and for the land to receive the end product.

Certificate of Approval

Off-farm sourced inputs, such as food processing byproducts, boost biogas production. In Ontario, to treat many of these materials, a Certificate of Approval (C of A) for both the on-site treatment facility and the

land-application of the digestate (the digester's end product) may be required.

Securing a C of A for the treatment facility will designate the farm or a component of the farm as a waste disposal site. This may trigger concern from neighbours who are unaware of the standards and operation of an anaerobic digester, and also has the possibility of affecting the zoning of the farm. Requiring a C of A for land application of the digestate will add additional criteria not required for manure application.

New Nutrient Management Act Regulation

A new regulation has been developed to streamline this regulatory process. This change to the *Nutrient Management Act* Regulation 267/03 allows the mixing of limited amounts of specified off-farm source materials into farm-based digesters for the purposes of manure treatment and energy production without the requirement of a C of A.

Off-farm material limits in this regulation include:

- <100 m^3 onsite at any one time prior to digestion (except for farm feed materials)
- <5,000 m^3/year
- <25% of the mix with farm source materials

This regulation has three lists of off-farm source materials. The first list specifies materials that are allowed to enter into a digester without any additional treatment. The second list specifies material requiring a guaranteed time/temperature treatment of 70°C for 1 hr or 50°C for 20 hr. The third list specifies materials that cannot be accepted for use in a digester.

If an operation wants to exceed the limits in the regulation or take materials not in the list, then a C of A will still be required for the treatment facility. However, this regulation allows the digestate from farm-based digesters to be treated as equivalent to manure as long as at least 50% of the inputs are agricultural-sourced material. This situation is true even if the system operates with a C of A.

NUTRIENT MANAGEMENT IMPLICATIONS OF ANAEROBIC DIGESTION SYSTEMS

The end product of AD systems has less organic matter than the material that was used as an input. As a result, the nitrogen that was tied up in organic matter converts to the ammonium form (Figure 8). When spreading this product in autumn, take up the ammonium-N with a standing crop or cover crop to prevent the nitrogen from leaching below the root zone.

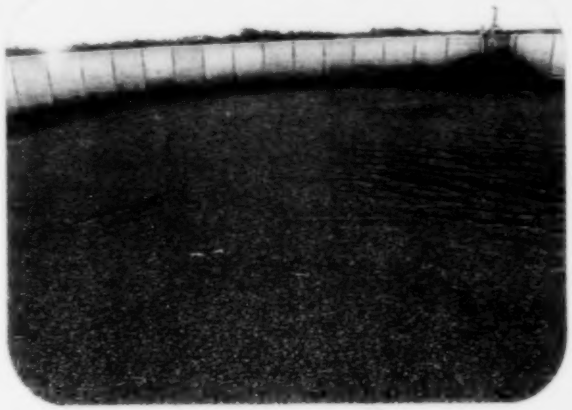

Figure 8. Covering the digested manure minimizes N loss from the storage. This system in Denmark uses a layer of small floating balls as the cover.

RESOURCES

Agriculture and Agri-Food Canada's ManureNet. http://res2.agr.ca/initiatives/manurenet/

OMAFRA. *Poop Power 2004*. Video outlining the operation of an on-farm Ontario anaerobic digester. Available on the OMAFRA website at www.ontario.ca/agengineering, under "Alternative Energy — Anaerobic Digestion — video"

U.S. Environmental Protection Agency's AgSTAR Program. www.epa.gov/agstar/

This Factsheet was authored by Jake DeBruyn, P.Eng., New Technology Integration Engineer, Environmental Management Branch, OMAFRA, Guelph, and Don Hilborn, P.Eng., Byproducts Management Engineer, Environmental Management Branch, OMAFRA, Woodstock.

Agricultural Information Contact Centre:
1-877-424-1300
E-mail: ag.info.omafra@ontario.ca
Northern Ontario Regional Office:
1-800-461-6132

www.ontario.ca/omafra

POD
ISSN 1198-712X
Également disponible en français
(Commande n° 07-058)

* 0 1 2 1 0 1 0 0 7 0 5 7 *